West Coast Regional Carbon Sequestration Partnership
westcarb.org

WESTCARB Geologic CO_2 Sequestration Field Tests

Fifth Annual
California Climate Change Conference
New Scientific Findings on Impacts, Mitigation, and Adaptation
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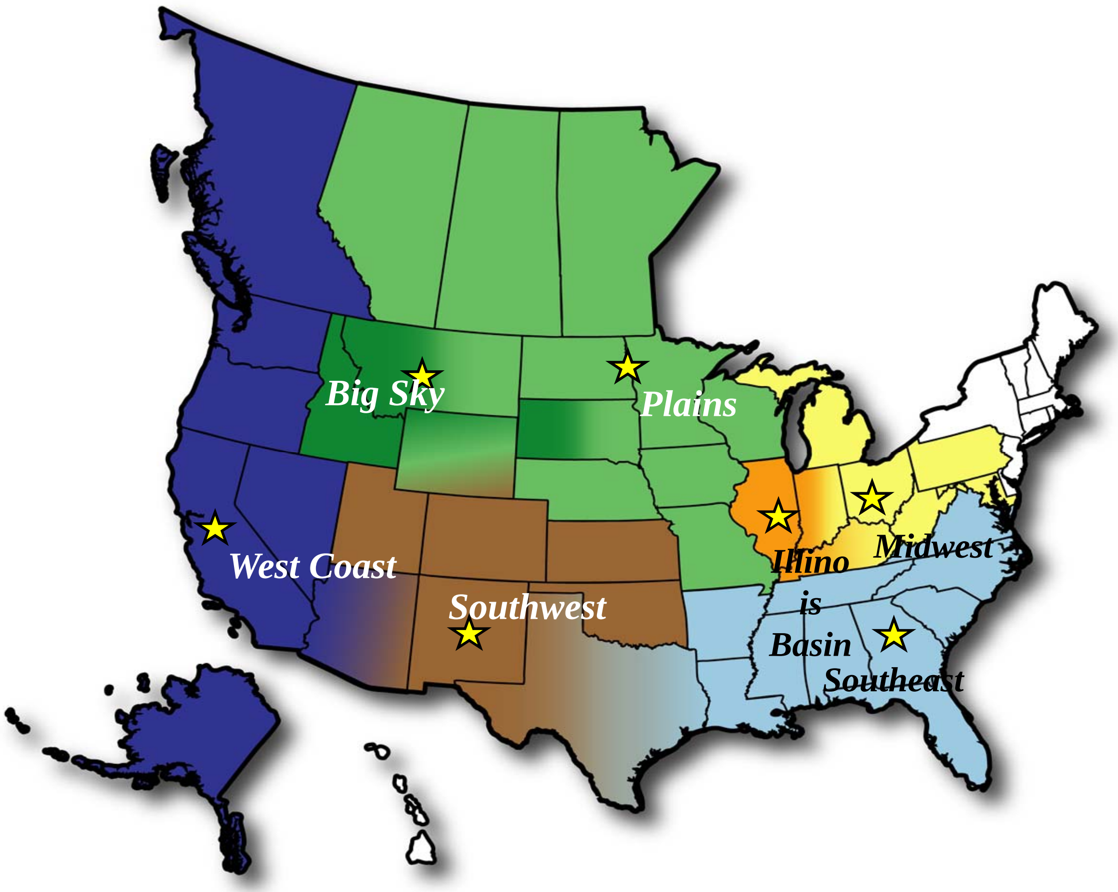
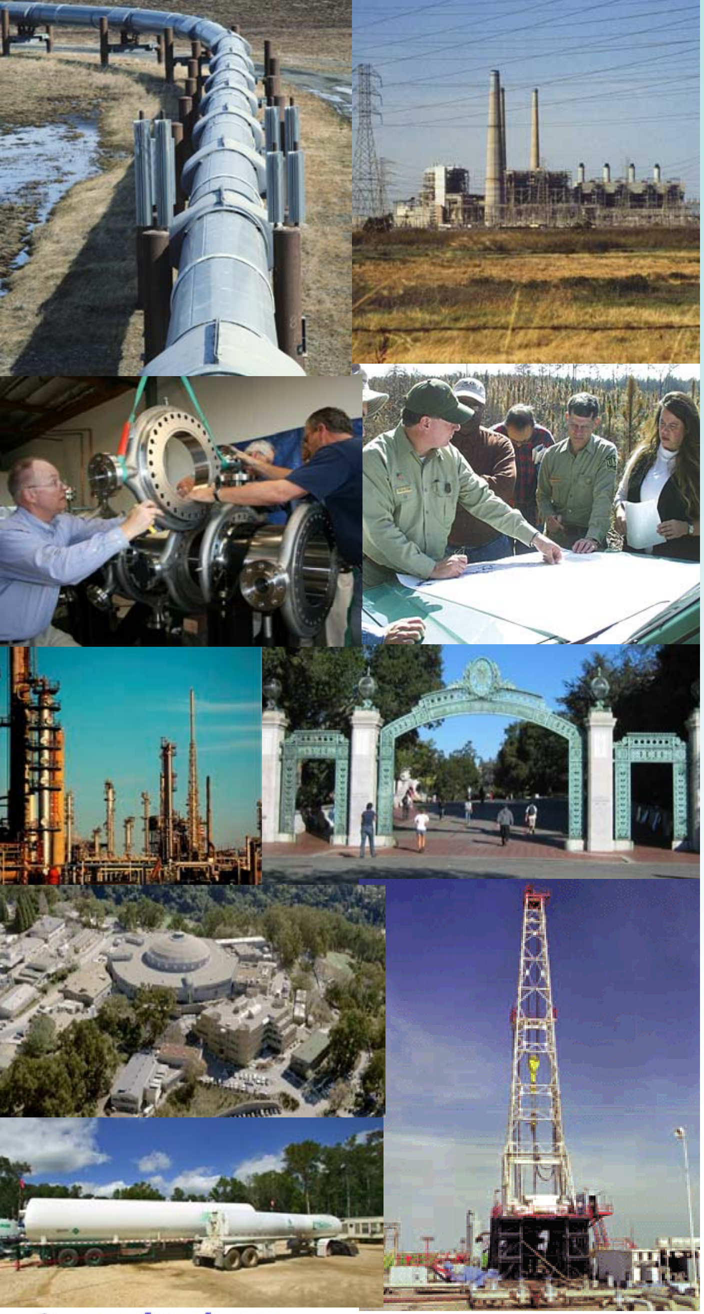
WESTCARB is one of seven DOE Regional Carbon Sequestration Partnerships

- U.S. Department of Energy program initiated in 2003 through the National Energy Technology Laboratory*
- Evaluating opportunities for geologic and terrestrial storage of CO_2 throughout the U.S. and Canada
- More than 350 participating organizations in the U.S. and Canada
- Focus on implementation issues



* http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html



WESTCARB has diverse partners contributing knowledge and dollars for CO_2 geologic storage

- WESTCARB is the West Coast Regional Carbon Sequestration Partnership
- It includes more than 80 organizations:
  - Resource management and environmental protection agencies
  - National laboratories and research institutions
  - Oil, gas, and pipeline companies
  - Conservation nonprofits
  - Climate project standards organizations
  - Colleges and universities
  - Trade associations
  - Service firms and consultants
- Led by the California Energy Commission
- Funded by U.S. Department of Energy, the Energy Commission, and industry partners

WESTCARB addresses technical and policy issues about carbon storage in a phased, applied R&D program

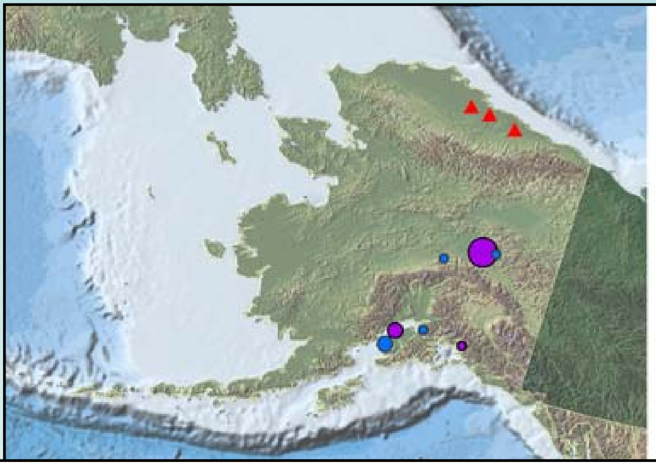
- **Identify regional CO_2 sources and how much they emit**
- **Identify locations where captured CO_2 can be stored**
- **Quantify the risks and determine the safety**
- **Develop and demonstrate methods to monitor CO_2 in the ground**
- **Estimate the cost and time scale for geologic storage**
- **Work with regulatory agencies to develop new standards for injection and storage of CO_2**
- **Inform the public about geologic storage of CO_2**

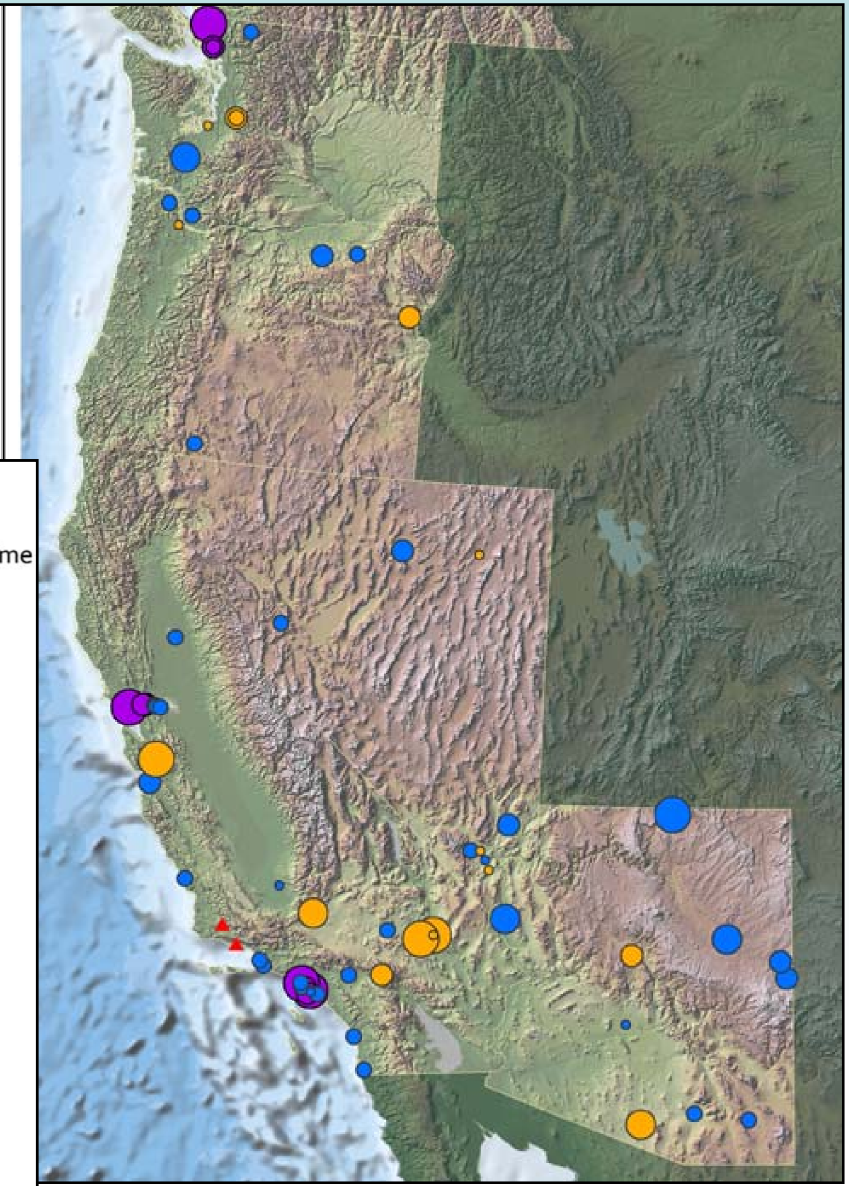
Phase I **Characterize regional CO_2 storage opportunities** (complete)

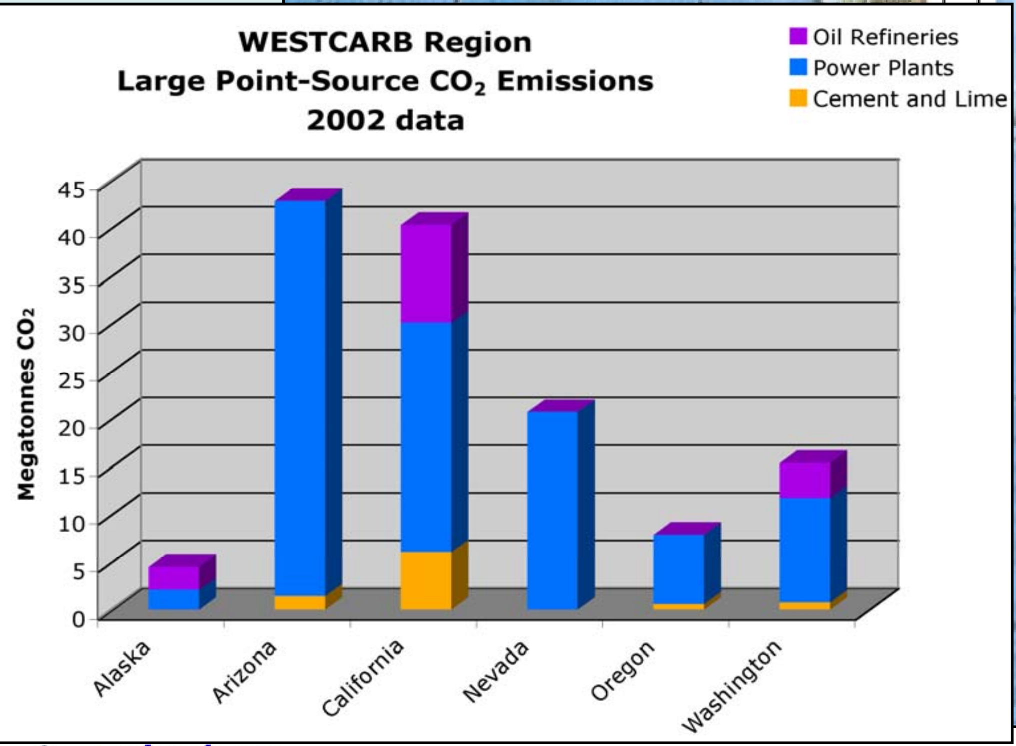
Phase II **Test promising geologic and terrestrial CO_2 storage options at pilot scale** (complete in Fall 2009)

Phase III **Pre commercial-scale geologic CO_2 storage test** (beginning in 2008)

WESTCARB region’s major CO_2 point sources





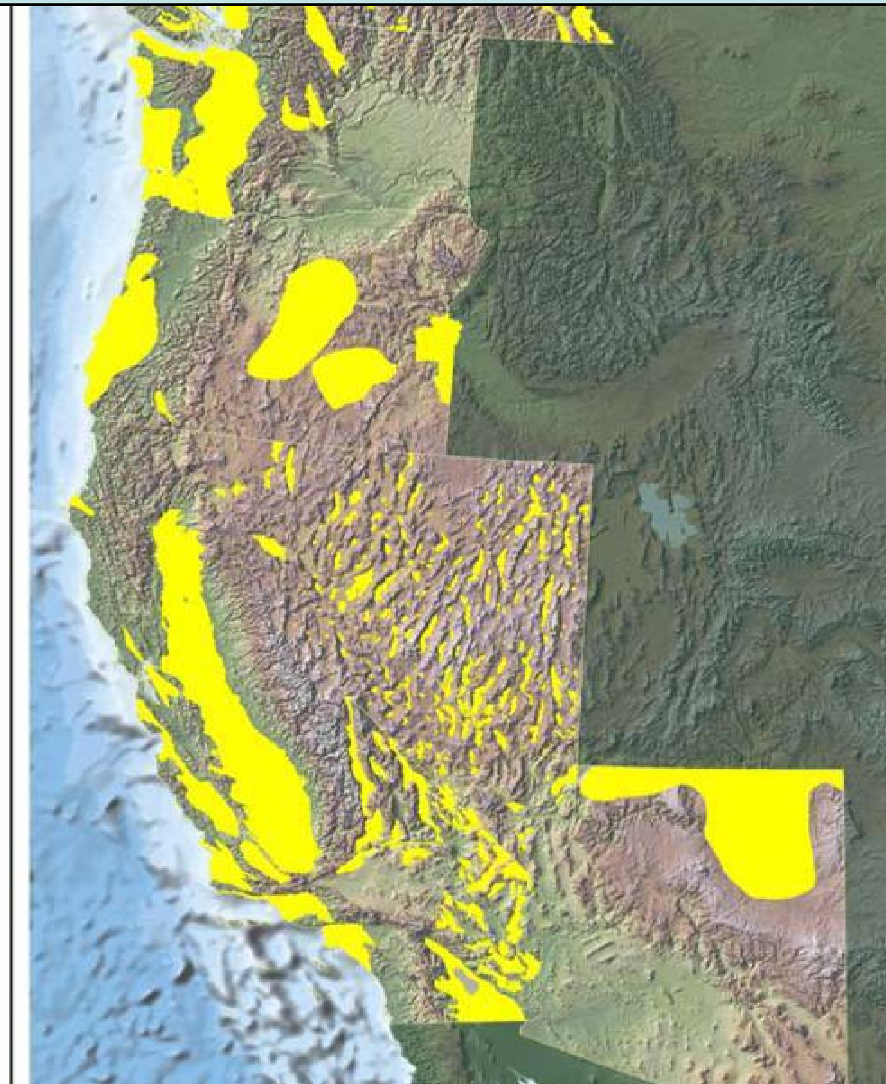


WESTCARB region has many deep saline formations – candidates for CO_2 storage

Source: *DOE Carbon Sequestration Atlas of the United States and Canada*

Deep Saline Formations

WESTCARB also created GIS layers for oil/gas fields and deep coal basins



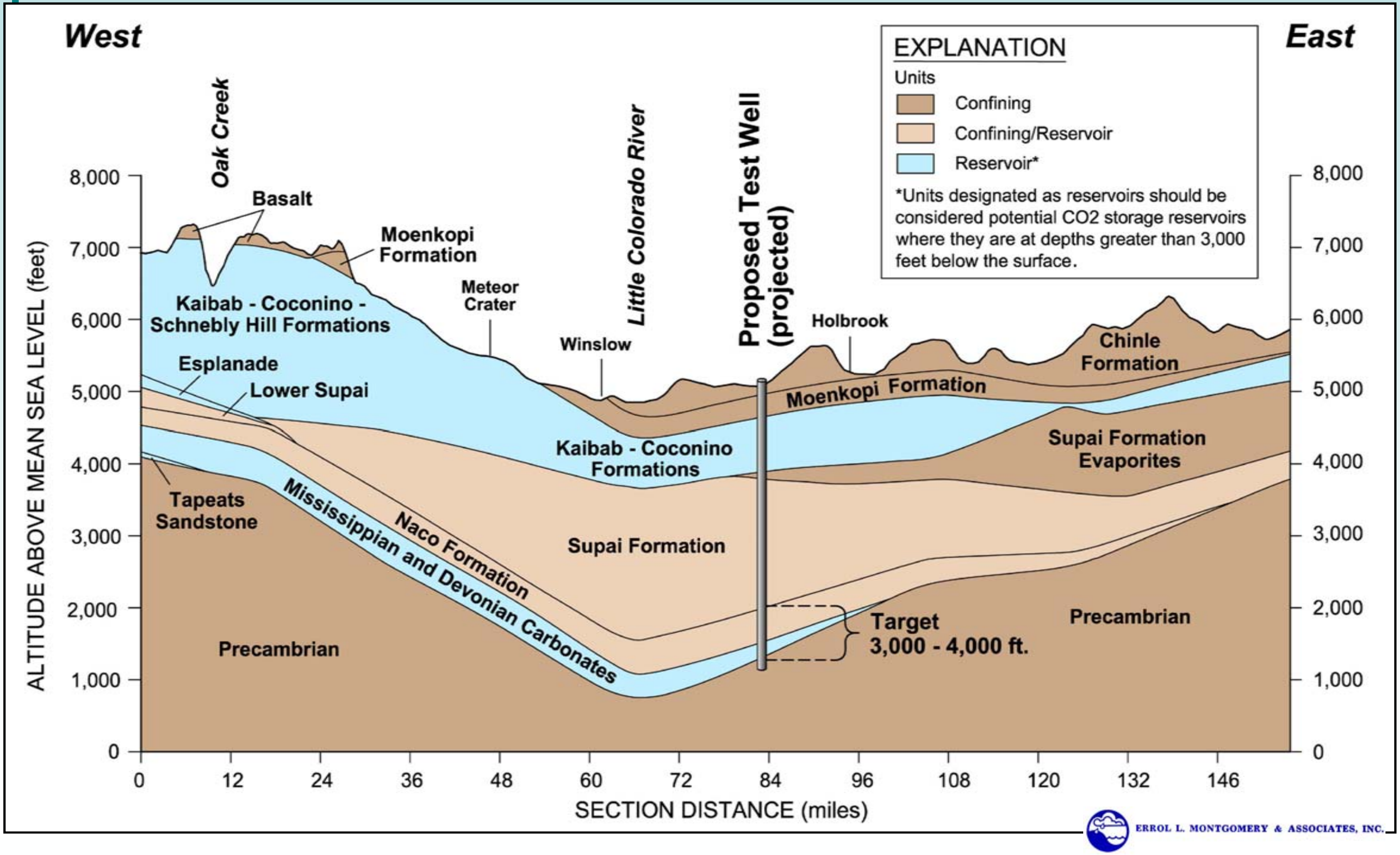
Arizona Utilities CO_2 Storage Pilot

- Arizona Public Service Company
- Salt River Project
- Tucson Electric Power
- Arizona Electric Power Cooperative
- National Rural Electric Cooperative Association
- Peabody Energy
- Electric Power Research Institute
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- California Energy Commission
- U.S. Department of Energy

Storage potential of Arizona geologic provinces

- Significant capacity in Colorado Plateau Province
- Limited capacity in Basin and Range Province
- Minor capacity in Central Highlands Province

Geologic section in Southern Colorado Plateau



Arizona Pilot Project Scientific Objectives

- Evaluate CO_2 sequestration opportunities in the southern Colorado Plateau
- Demonstrate safe storage of CO_2 in porous carbonate formations containing non-potable, saline water beneath thick, low permeability cap rock
- Determine injectivity and storage capacity of the reservoir
- Develop, calibrate, and validate multiphase flow models for CO_2 injection into saline formations typical of northeastern Arizona
- Show that surface and borehole geophysical techniques can image CO_2 in the subsurface and detect leaks
- Assess caprock integrity
- Assess potential environmental impacts - surface leakage, groundwater

Arizona Pilot Project Test Plan

- Numerical simulation of CO_2 injection
- Drill and log a single well ~4,000 ft (1,200 m) deep near the APS Cholla Power Plant fly ash pond
- Ensure TDS of reservoir formation >10,000 mg/L
- Step-rate injection test to determine maximum injection pressure
- CO_2 huff-puff test for residual saturation estimate
- Inject 2,000 tonnes of commercial-grade CO_2
- Sample fluids with U-tube system; chemical analysis
- Pre- and post-CO_2 injection monitoring
  - Reservoir Saturation Tool (RST) logs
  - Vertical seismic profile (VSP) surveys
  - Distributed Thermal Perturbation Sensor (DTPS) logs
- Vent CO_2 from well; analyze fluids with phase-partitioning tracers

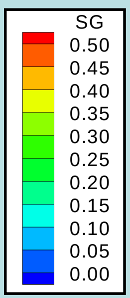
TOUGH2 Simulation of CO_2 injection

High horizontal permeability
Low vertical permeability
Hysteretic effects included

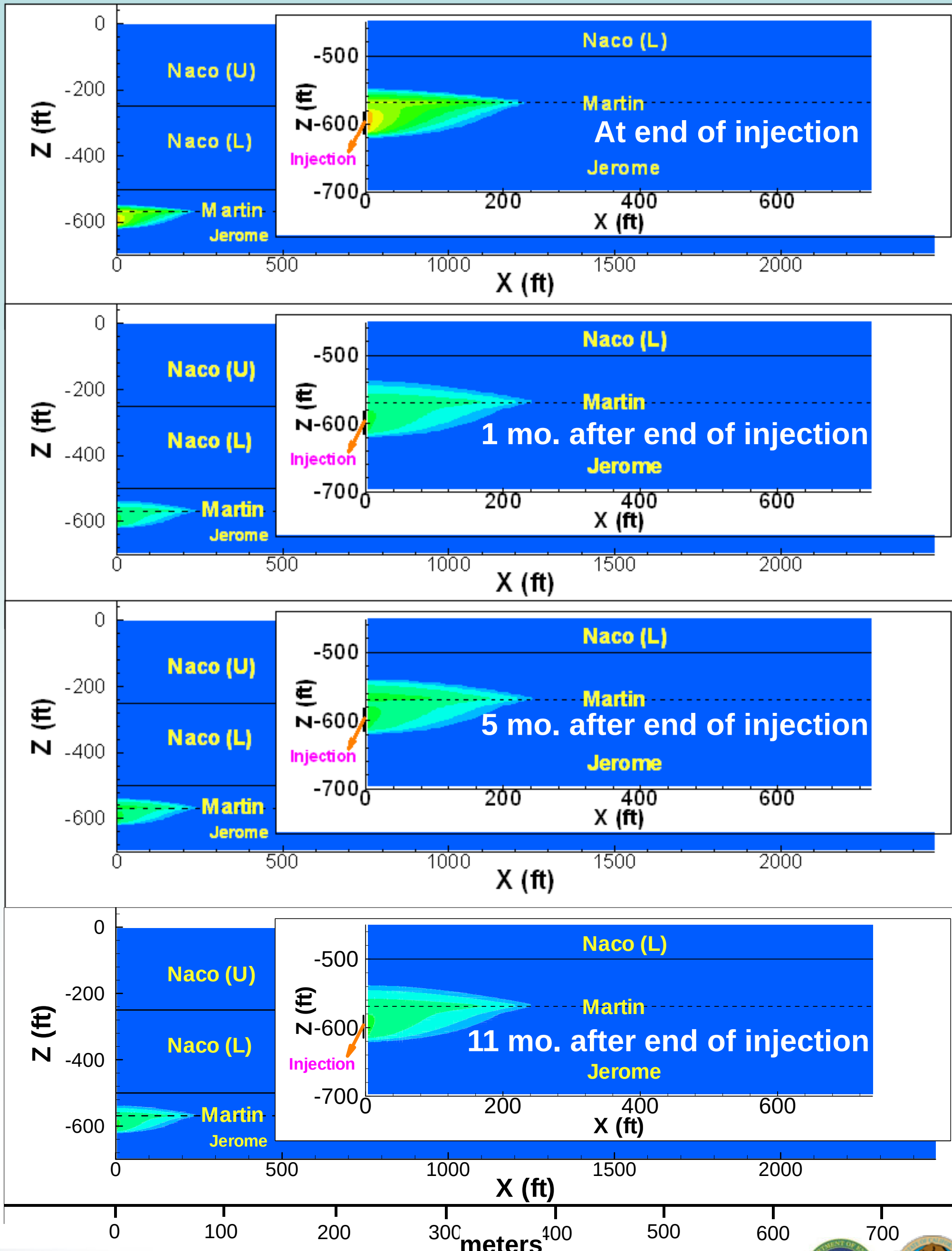
Formation	Thickness	k_h (mD)	k_v (mD)
Upper Naco	76 m (250 ft)	10	1
Lower Naco	76 m (250 ft)	100	3
Upper Martin	21 m (69 ft)	100	3
Jerome	40 m (131 ft)	700	20

2,000 tonnes injected over 30 days (0.8 kg/s) into Jerome Member of Martin Formation

- **Depth = 1,100 m (3,700 feet)**
- **P = 10.3 MPa (1500 psi) [hydrostatic]**
- **T = 54°C (129°F) [normal gradient]**
- **Porosity = 10%**
- **Residual saturation for drainage, S_{gr} = 0%**
- **Residual saturation for imbibition, S_{gr} = 25%**



Gas saturation
Fraction of pore space filled by supercritical CO_2



TOUGH2 simulation of pressure during CO_2 injection

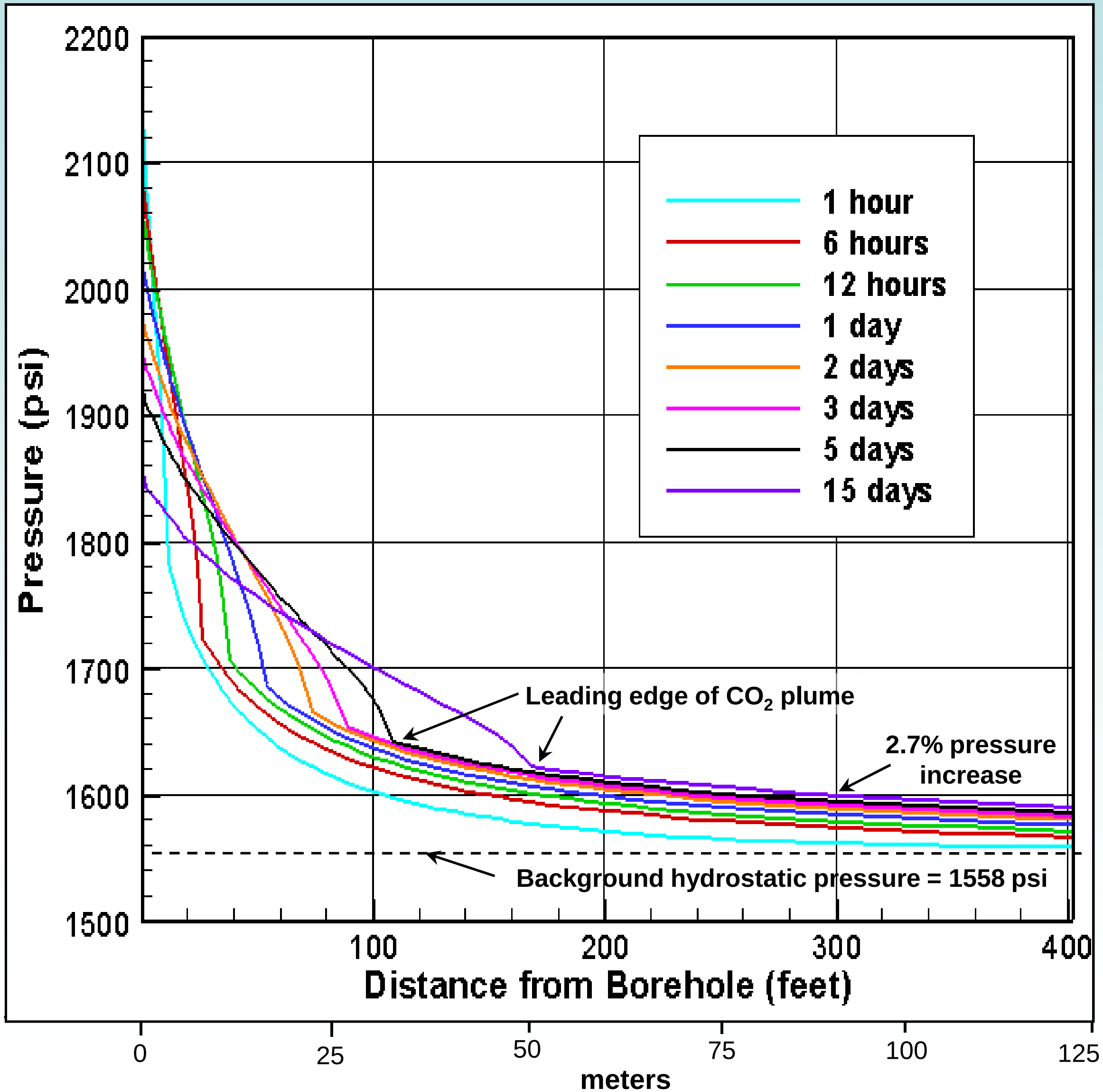
Pressure in reservoir formation at injection depth

High horizontal permeability

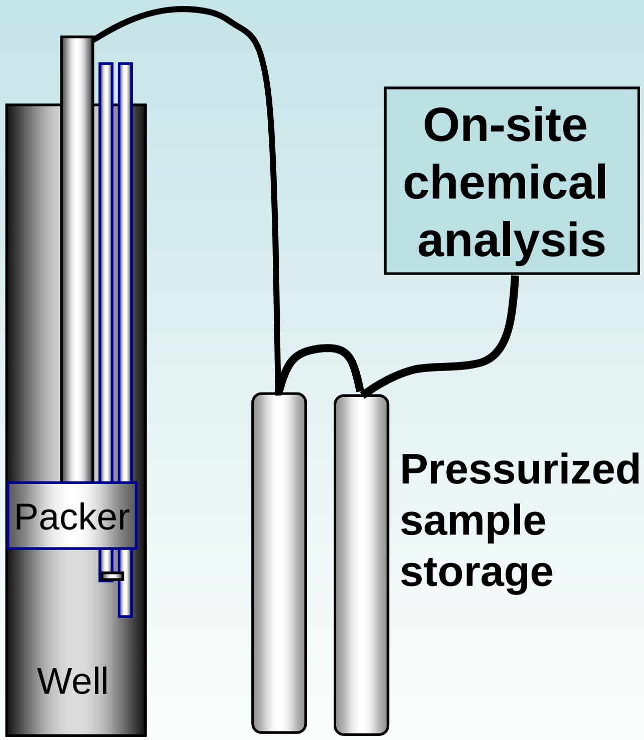
Formation	Thickness	k_h (mD)	k_v (mD)
Upper Naco	76 m (250 ft)	10	1
Lower Naco	76 m (250 ft)	100	3
Upper Martin	21 m (69 ft)	100	3
Jerome	40 m (131 ft)	700	20

2,000 tonnes injected over 15 days (1.6 kg/s)
into Jerome Member of Martin Formation

- Depth = 1,100 m (3,700 feet)
- P = 10.4 MPa (1558 psi) [hydrostatic]
- T = 54°C (129°F) [normal gradient]
- Porosity = 10%
- Residual saturation for drainage, S_{gr} = 0%

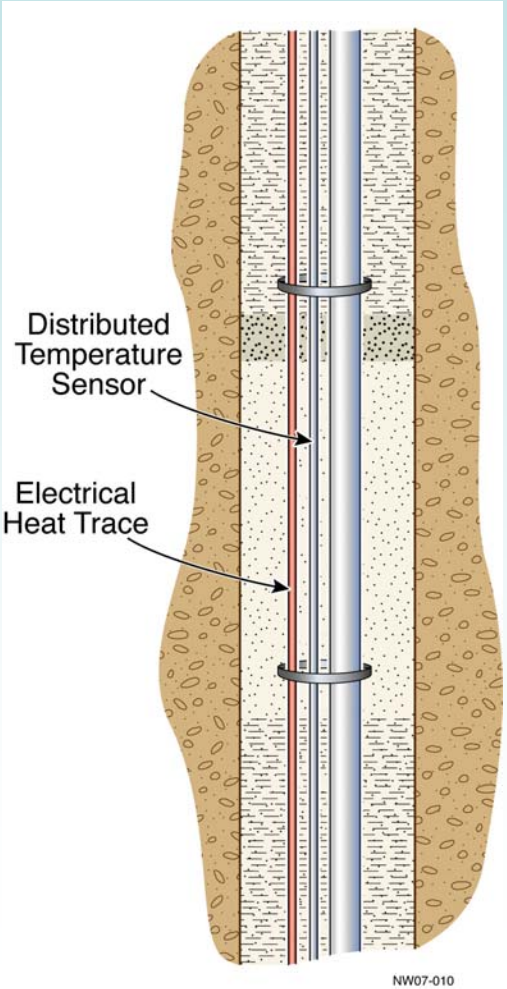


U-Tube System – continuous water, CO_2, and tracer samples at reservoir pressure



U-tube and check valve strapped to production tubing

Distributed Thermal Perturbation Sensor (DTPS) for tracking CO_2 migration in the subsurface

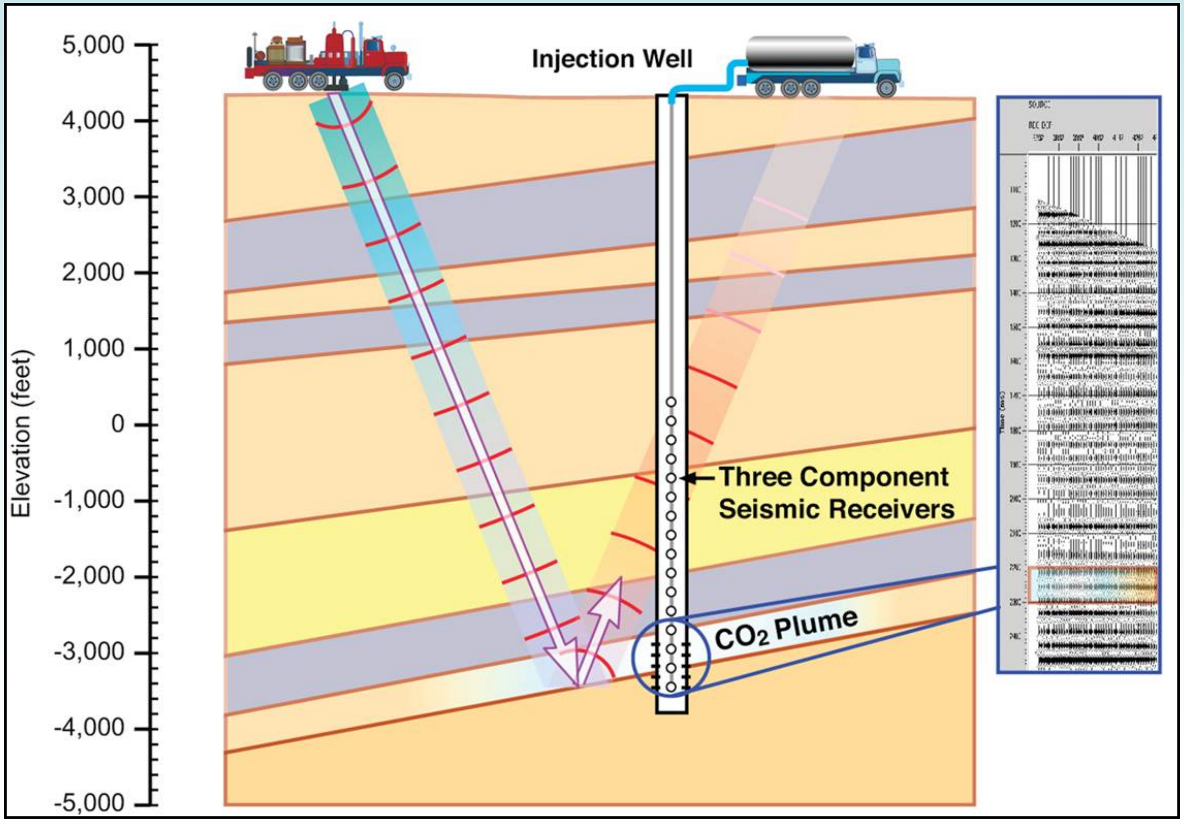


Thermal conductivity measurements during and after CO_2 injection monitor the distribution of CO_2 near the well

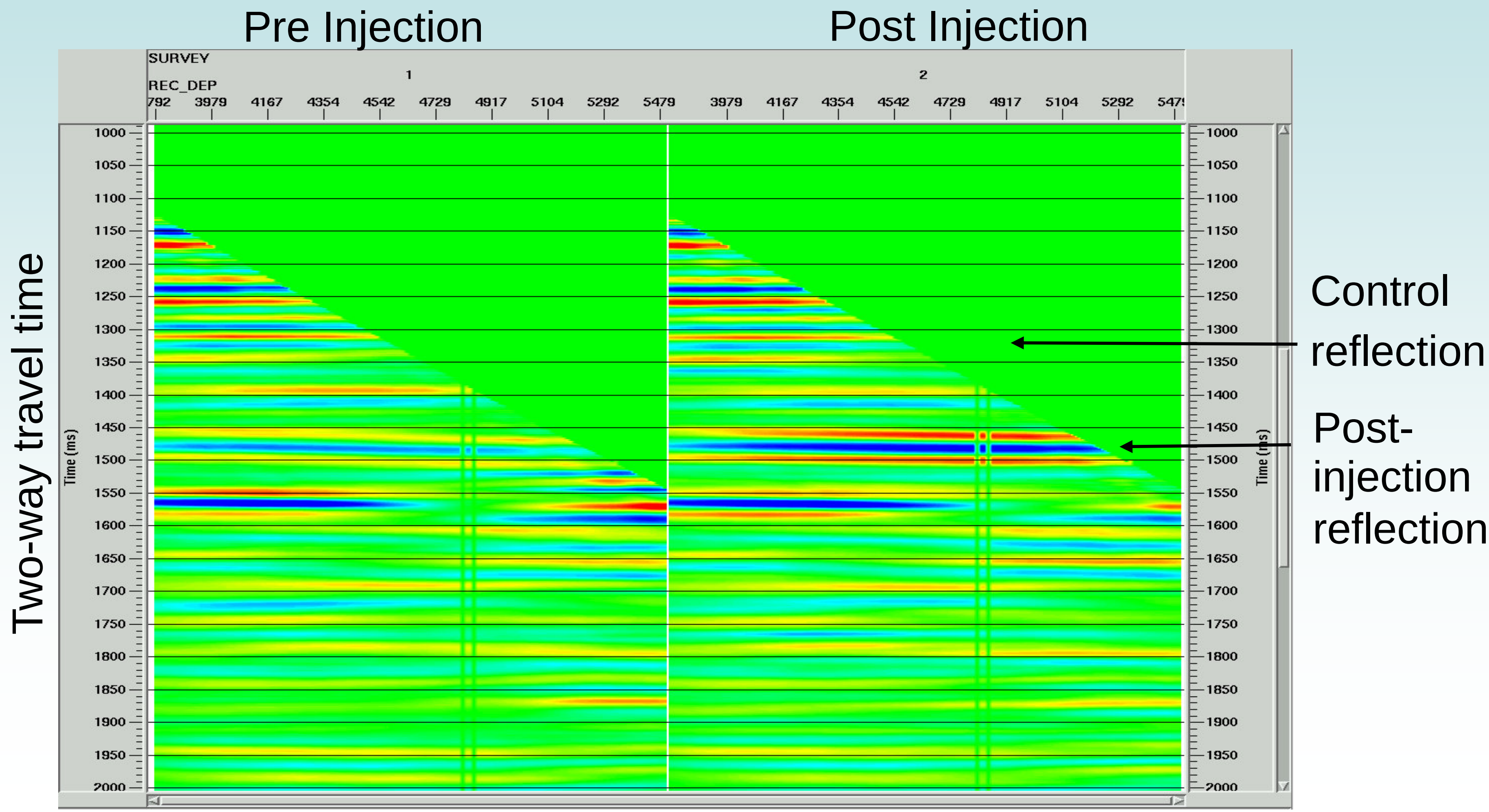
- **The DTPS consists of a borehole-length electrical resistance heater and fiber optic distributed temperature sensor**
- **Constant heating is applied along the borehole, then is turned off. The temperature sensor measures the decay**
- **The low thermal conductivity of CO_2 versus water allows for estimates of CO_2 saturation**
- **The DTPS has been successfully tested at the CO2SINK project in Germany**

Vertical Seismic Profile (VSP) Survey

- To be performed in time-lapse mode, pre- and post-CO_2 injection
- Supercritical (liquid-like) CO_2 displaces some formation water and reduces seismic velocity



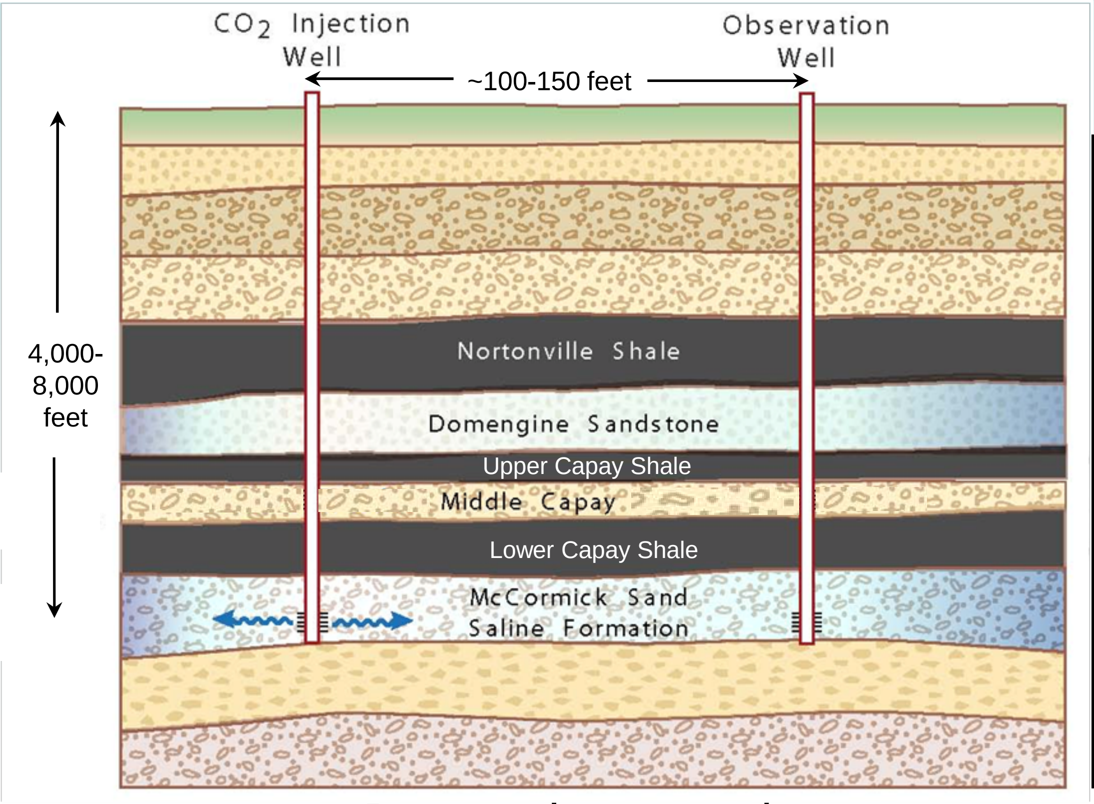
VSP detection of 1,600 tonnes of CO_2 at Frio Test Site in Texas



(T. Daley, LBNL, 2005)

California CO_2 Storage Pilot

Site Geologic Attributes:
- Multiple seals
- High permeability saline reservoir



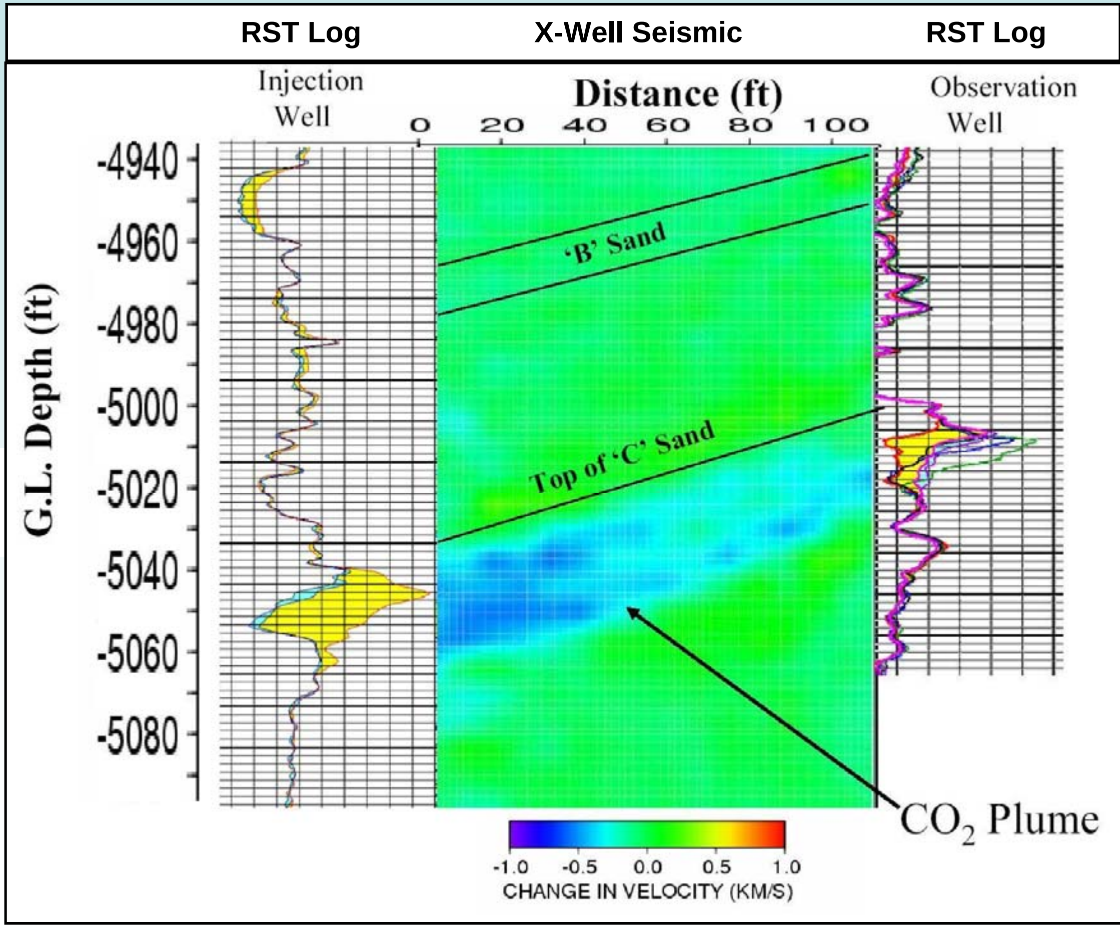
Representative cross-section

Field Operations:
- Drill two wells penetrating reservoir
- Inject 2,000 tonnes of CO_2 into a saline formation
- Assess injectivity and storage capacity
- Monitor subsurface CO_2 movement
- Test for leakage

Monitoring the CO_2 plume

- Seismic imaging
  - Time lapse VSP
  - Time lapse crosswell
  - Controlled-Source Active Seismic Monitoring (CASSM)
  - Correlate seismic with fluid and tracer samples obtained with U-tube
- Time lapse Reservoir Saturation Tool (RST)* log

* Schlumberger tool that measures thermal neutron absorption to infer water saturation, and C/O ratio with an induced gamma ray spectrometer.



Frio CO_2 Test Site, Texas

Regulatory Agencies & Permits

- Experience with permitting pilot projects
  - Injection permit: US EPA Underground Injection Control (UIC) Program – Class V, Experimental
    (New draft regulations for Class VI, CO_2 wells)
  - Drilling permit in oil/gas field: CA Department of Oil, Gas and Geothermal Resources
  - Drilling permit in saline aquifer: County agency
  - NEPA: DOE Environmental Questionnaire
  - CEQA: Lead state or local agency; CEC approval

Agreements & Contracts

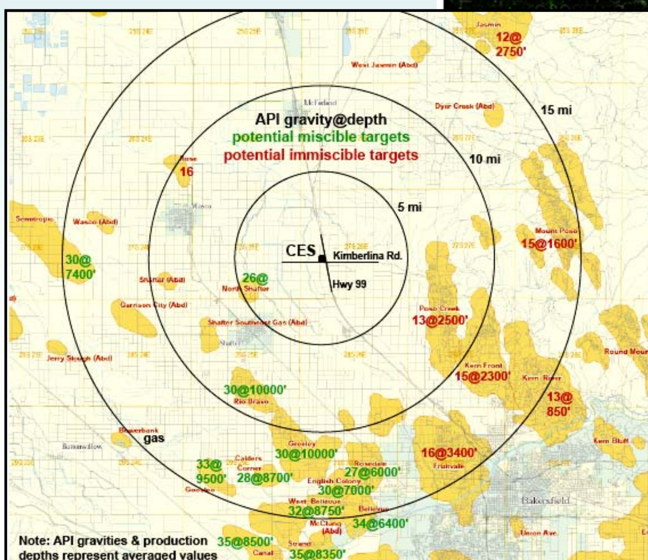
- Experience with contracting for pilot projects
  - Surface owner
  - Mineral rights owner
  - Mineral rights leaseholder
  - Pore space owner *(surface owner in Wyoming)*
  - Agreements among project partners
  - Contracts with subcontractors and suppliers
  - Adjacent mineral/pore space owners (subsurface trespass)
  - Adjacent surface owners for VSP source points

WESTCARB Phase III Objectives

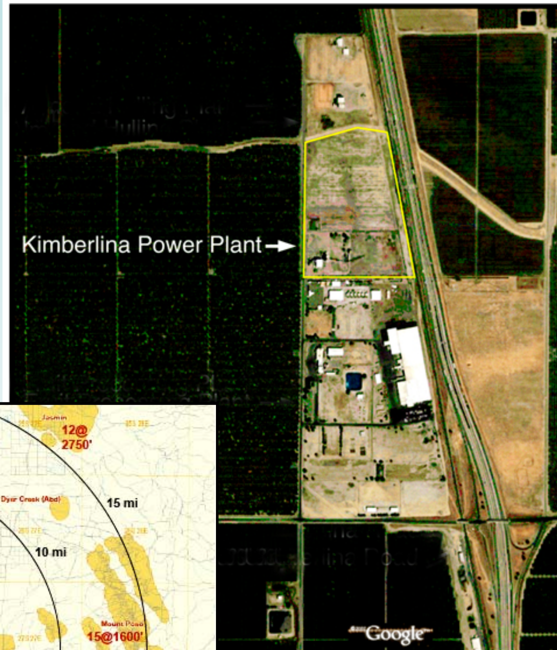
- Conduct a commercial-scale Carbon Capture and Storage test injecting1 million tons of CO_2);nominal 10-year project
  - Access the best geologic target in California
  - Refine capacity estimates and “qualify” the target formations (Olcese and/or Vedder) for commercial application
- Co-locate project with advanced, commercial “sequestration friendly” oxy-combustion technology (Clean Energy Systems)
  - Technology development supported by DOE and CEC
  - Planned as first commercial-scale facility of its type in U.S.
- Demonstrate commercial-scale injection site characterization, operations, maintenance, and monitoring (Schlumberger)
- Conduct research to improve technologies for reservoir modeling/simulation and engineering, risk assessment, and measurement/monitoring (LBNL, LLNL, Stanford)
- Establish in the public mind—via direct proof—that emission-free fossil power is possible and geologic sequestration is safe

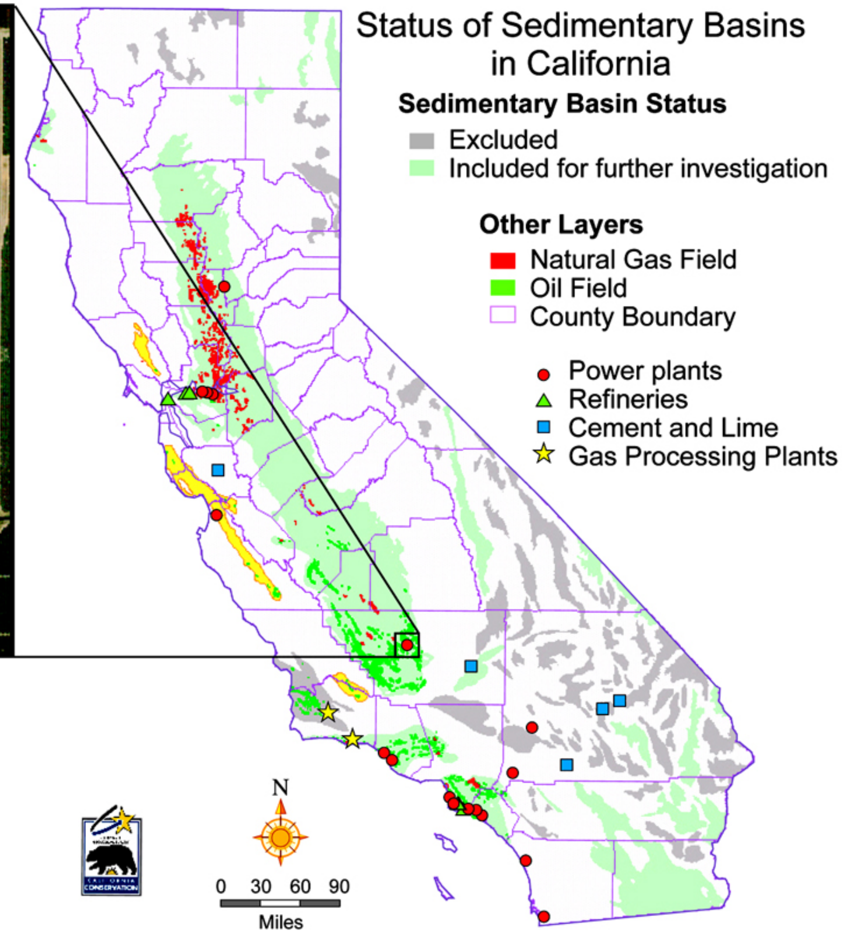
Project is representative of major California sequestration/EOR potential – provides underpinnings for commercialization

Many nearby oilfields are EOR-suitable



(J. Johnson, LLNL)



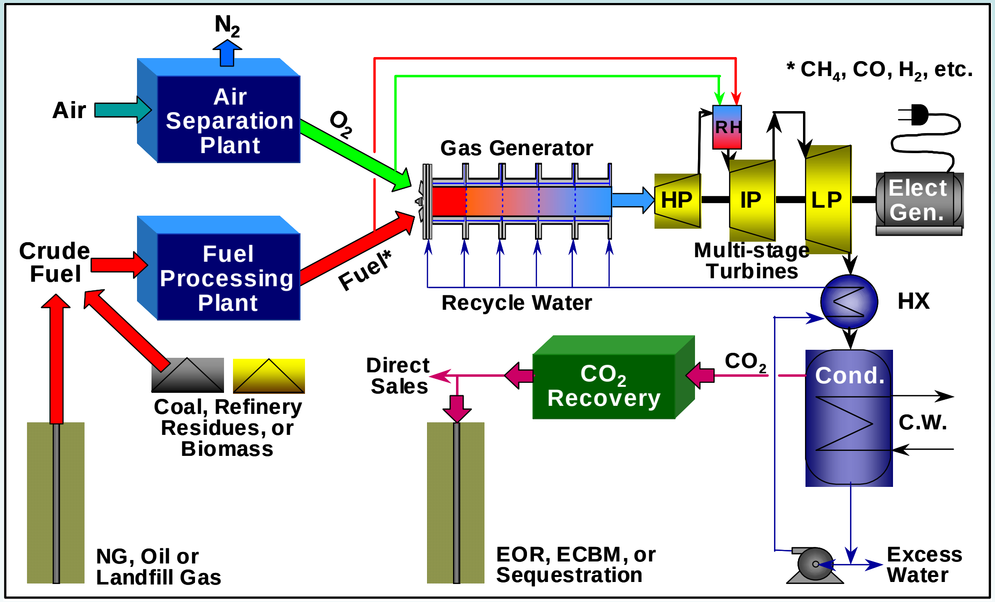


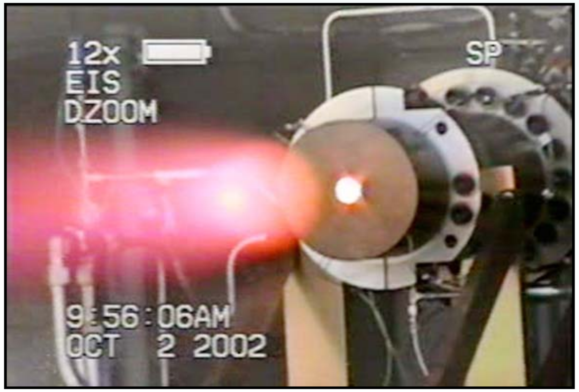
Source: *California Geological Survey*

WESTCARB Phase III site co-located with CES zero-emissions power plant

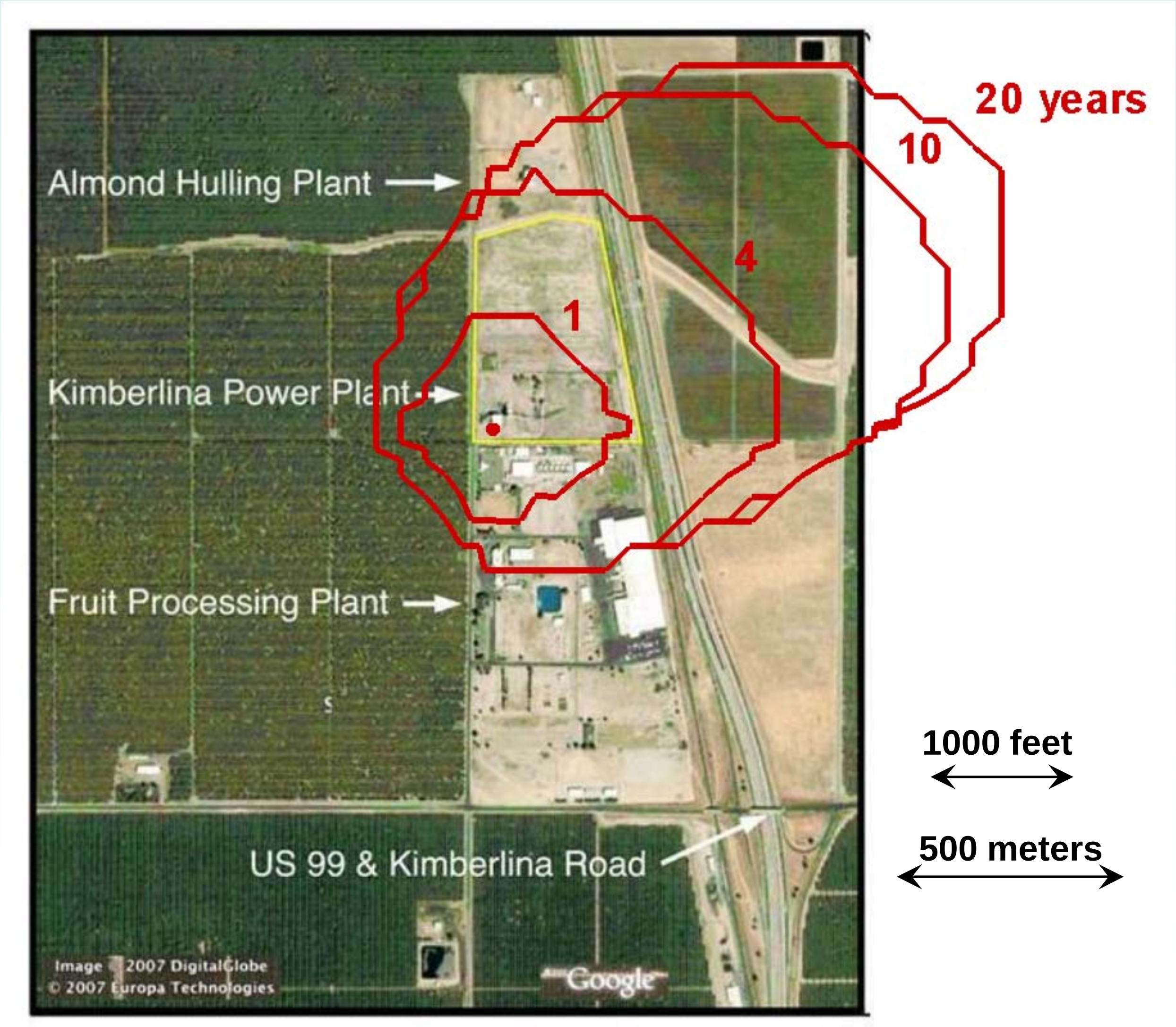
- CES will build a 49 MW power plant near Bakersfield, CA
- Plant will provide ~250,000 tons of CO_2 per year for four years
- CO_2 injectivity test in 2009-10, full scale injection in 2010-11
- One injection well and one monitoring well
- Initial geologic modeling, reservoir simulation, and risk assessment under way

Clean Energy Systems' generation technology

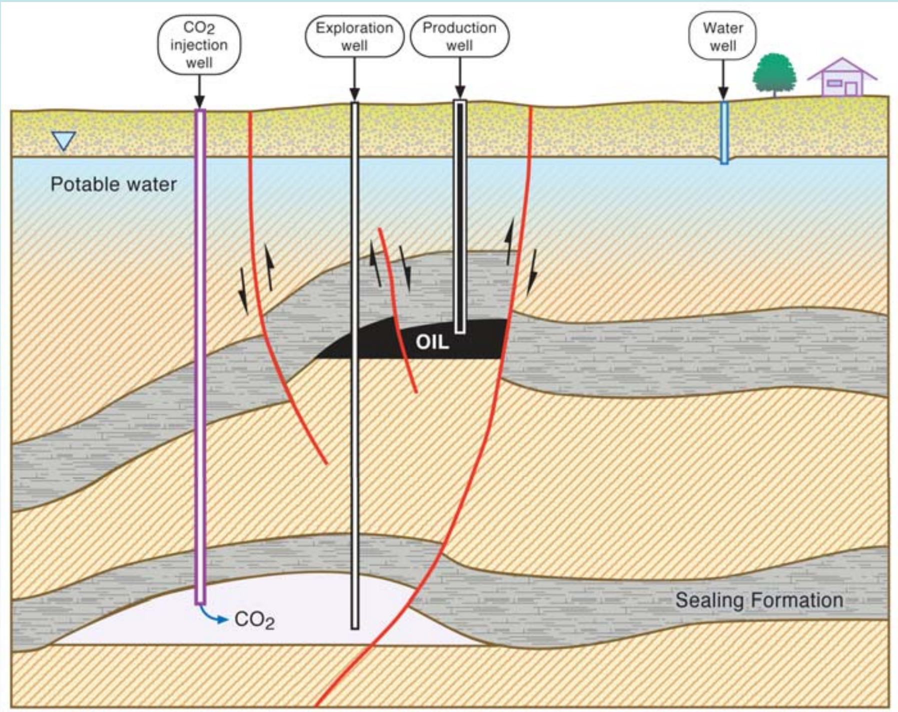


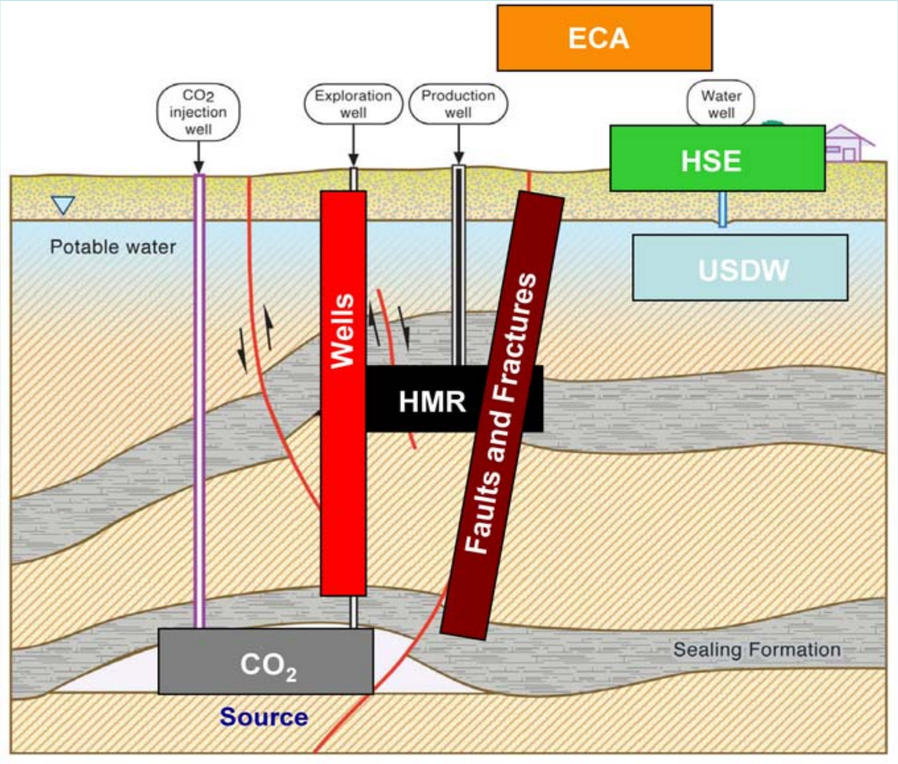


Projected surface footprint of plume over time affects project planning



Risk assessment methods developed in Carbon Capture Project 2 being applied





Four compartments vulnerable to impacts:

- ECA - Emission credits and atmosphere
- HSE - Health, safety, and environment
- USDW - Underground sources of drinking water
- HMR - Hydrocarbon and mineral resources

Two conduits with potential for leakage:

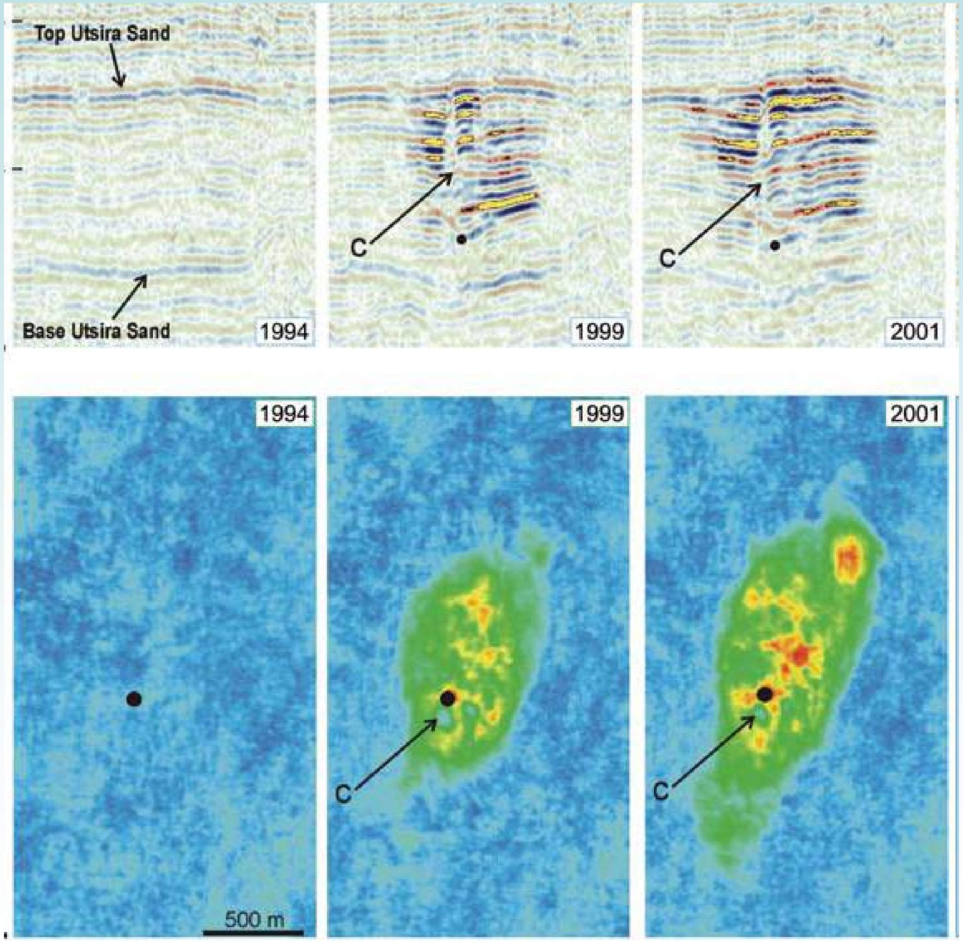
Wells, Faults and Fractures

CO_2 Leakage Risk is probability that negative impacts will occur to HMR, USDW, HSE, or ECA due to CO_2 migration

Source: *C. Oldenburg, LBNL*

Monitoring the CO_2 plume

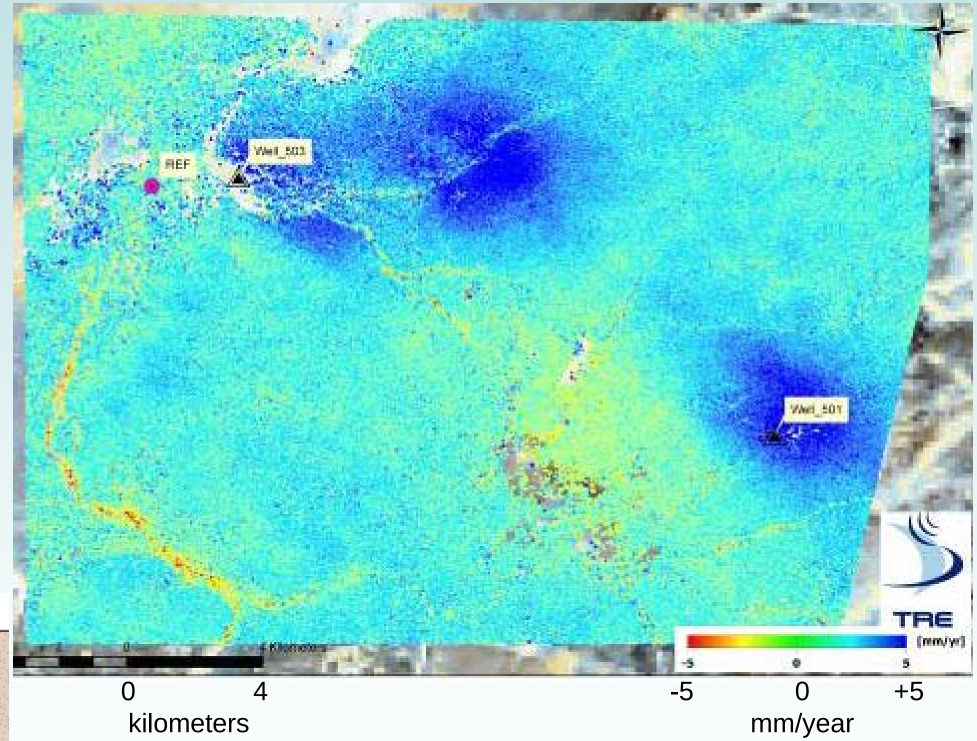
- Well logs
- Formation fluid sampling
- Active source thermal logging
- Surface monitoring near wells
- **Microseismic monitoring**
- **Time-lapse 3D seismic**



Time-lapse 3D seismic results at Statoil's Sleipner project, North Sea
(Chadwick, 2004)

Research-stage monitoring methods will be explored

- PSInSAR (Permanent Scatterer Synthetic Aperture Radar Interferometry) could provide inexpensive picture of pressure distribution
- Novel deployment and analysis of surface seismic for plume boundary monitoring
- Possible application of electromagnetic methods
- Processing/joint inversion



Time lapse PSInSAR data showing surface displacement due to CO_2 injection at Gas Processing Plant, In Salah, Algeria

Source: *J. Rutqvist, D. Vasco, LBNL*